

5 This application claims priority to an application entitled “WAVELENGTH
DIVISION MULTIPLEXING LIGHT SOURCE APPARATUS USING
SEMICONDUCTOR OPTICAL AMPLIFIER,” filed in the Korean Intellectual Property
Office on March 17, 2003 and assigned Serial No. 2003-16373, the contents of which are
hereby incorporated by reference.

1. Field of the Invention

The present invention relates to a Passive Optical Network (PON) using Wavelength Division Multiplexing (WDM).

2. Description of the Related Art

Most broadcast and communication service subscribers currently use data communication services such as Internet at rates of about several tens of Kbps (bits per second) to several tens of Mbps. These rates are achieved through xDSL, a cable modem, a dial-up modem, metro-Ethernet, etc. Subscribers also use broadcasting services such as

cable broadcasting through a coaxial cable, satellite broadcasting through a satellite, terrestrial broadcasting, etc.

Data rates of about 100 Mbps are required to effectively provide subscribers with services such as high-capacity image information, VoD (Video on Demand), and high-quality digital broadcasts. However, the prior art has many limitations in accommodating such data in terms of its capacity and speed. Accordingly, there is a need for implementing an optical network using optical communication. To this end, PON technology has been proposed and developed as an economic way to implement an optical network.

The PON is classified mainly into an Asynchronous Transfer Mode (ATM)-PON, an Ethernet-PON, and a WDM-PON according to its implementation methods.

The ATM-PON and Ethernet PON have a number of limitations including (1) no transparency regarding the speed of data to be provided to subscribers, and (2) complicated Media Access Control (MAC) technologies are required for an Optical Line Terminal (OLT) because the same wavelength is used in the upstream transmission. The ATM-PON and Ethernet PON also have a problem in that it is difficult to accommodate digital broadcasts.

The WDM-PON does not have the limitation on the speed of data, and also does not require a complicated MAC technology. In addition, it is easy for the WDM-PON to accommodate digital broadcasting services.

Fig. 1 shows one prior-art example of a WDM-PON that integrates broadcast and communication services. As shown, the WDM-PON includes an Optical Line Terminal (OLT) 11, Optical Network Terminal/Optical Network Unit (ONT/ONUs) 12, an optical

splitter 15, a photoelectric (or optical-to-electrical) converter (O/E) 16, a Radio Frequency (RF) splitter 17, a WDM demultiplexer 13, and a WDM multiplexer 14. The OLT 11 is connected to a broadcasting network for broadcasting services and an Internet Protocol (IP) network for communication services. The OLT 11 receives broadcast signals from the broadcasting network and communication signals from the IP network. The OLT 11 transmits the received signals as optical signals after their photoelectric conversion. In addition, the OLT 11 transfers communication signals, received from service subscribers, to the IP network. The ONT/ONUs 12 are devices on the user side for transferring the broadcast and communication signals, received from the OLT 11, to service users and transferring communication signals from the service users to the OLT 11. The optical splitter 15 splits the broadcast and communication signals from the OLT 11 into a broadcast signal λ_A and communication signals λ_1 to λ_{32} , and transmits them. The photoelectric converter 16 photoelectrically converts the broadcast signal λ_A split through the optical splitter 15. The RF splitter 17 distributes the converted electric broadcast signal to each of the ONT/ONUs 12. The WDM demultiplexer 13 WDM-demultiplexes the communication signals λ_1 to λ_{32} , and transfers them to the ONT/ONUs 12. The WDM multiplexer 14 WDM-multiplexes the communication signals λ_1 to λ_{32} from the ONT/ONUs 12, and transfers them to the OLT 11. λ_1 to λ_{32} are used as wavelength channels for communication, and λ_A is used as wavelength channels for broadcasting.

Operationally, a broadcast signal λ_A in downstream transmission is optically split through the optical splitter 15 in the front end of the WDM demultiplexer 13. Then it is

photoelectrically converted in the photoelectric converter (O/E) 16. After the converted signal is separated into broadcast signals corresponding respectively to service users through the RF splitter 17, they are transmitted to the respective service users through a coaxial cable.

- 5 After being demultiplexed in the wavelength demultiplexer 13 on a wavelength-by-wavelength basis, the communication signals λ_1 to λ_{32} are transmitted to the respective service users.

Disadvantageously, in such a prior art system, the transmission of broadcast and communication signals are not integrated in one wavelength. Instead, the broadcast signal
10 is transmitted with its analog and digital broadcast signals integrated in one wavelength λ_A . The communication signals are provided to respective subscribers through wavelengths λ_1 to λ_{32}

In addition, in such a prior art system, the optically-split broadcast signal λ_A is photoelectrically converted. Its analog and digital broadcast signals are transmitted through
15 a cable network. Such a cable network is installed to provide the existing broadcasting services defined in bands up to around 550MHz. However, it is impossible to accommodate analog/digital broadcasts using the existing cable network because the domestic digital cable broadcasting standard was established to have a band of around 850 MHz for analog and digital broadcast signals.

- 20 Thus, in order to accommodate analog/digital broadcasts, such a system (1) requires the lead-in coaxial cable in each subscriber to be replaced with a coaxial cable of an

extended band, or (2) to install a new extension coaxial cable with the existing coaxial cable being retained.

Fig. 2 shows another prior-art example of a WDM-PON that integrates broadcast and communication services. As show, the WDM-PON includes an OLT 21, ONT/ONUs 22, a WDM demultiplexer 23, and a WDM multiplexer 24. The OLT 21 is connected to a broadcasting network for broadcasting services and an IP network for communication services. The OLT 21 receives broadcast signals from the broadcasting network and communication signals from the IP network, and transmits the received signals as optical signals after their photoelectric conversion. The OLT 21 further transfers communication signals, received from service subscribers, to the IP network. The ONT/ONUs 22 are devices on the user side for transferring the broadcast and communication signals, received from the OLT 21, to service users, and transferring communication signals from the service users to the OLT 21. The WDM demultiplexer 23 WDM-demultiplexes both the communication signals λ_1 to λ_{32} and the broadcast signals λ_{33} to λ_{64} , and transfers them to the ONT/ONUs 22. The WDM multiplexer 24 WDM-multiplexes the communication signals λ_1 to λ_{32} from the ONT/ONUs 22, and transfers them to the OLT 21.

In such a prior art system, it is possible to provide high-capacity data communication and broadcasting services because wavelengths for broadcast and communication are given individually to each of subscribers. However, as with the prior art system of Fig. 1, this system does not provide for integrated transmission of the broadcast and communication signals. In addition, this system must include twice as many

optical transmitters as the prior art system of Fig. 1. In addition, each subscriber must use two optical receivers in order to receive both a communication wavelength signal and a broadcast wavelength signal. This causes an increase in the cost of the WDM-PON system, consequently imposing a burden on the subscribers. Further, in the WDM-PON, the number of subscribers coincides with the number of wavelengths. Thus, the prior art system of Fig. 2 has a further limitation in that it can handle only half the number of subscribers as compared to the prior art system of Fig. 1, because each subscriber uses two wavelengths.

SUMMARY OF THE INVENTION

Therefore, the present invention has been made to reduce or overcome the limitations of the prior art. One object of the present invention to provide a passive optical network wherein digital broadcasting services and communication services are integrated and transmitted using wavelength division multiplexing).

Another object of the present invention is to provide high-speed and high-capacity data and broadcasting services using a WDM-PON. In addition, to accommodate analog broadcast services by utilizing the installed coaxial cable base, whereby it is possible to comply with the domestic digital cable standard with no need to replace the existing coaxial cable.

Still another object of the present invention is to multiplex a digital broadcast signal and a communication data signal in an OLT so as to provide the signals to each subscriber

through a single wavelength. Thus, each subscriber requires only one optical transmitter and one optical receiver, thereby achieving a low-priced WDM-PON system. In addition, the broadcast and communication signals are transmitted in an integrated single wavelength, thereby making it easier to secure transmittable channels.

5 In accordance with one aspect of the present invention, a WDM-PON (Wavelength Division Multiplexing-Passive Optical Network) is provided that enables the integration of broadcast and communication services. The WDM-PON includes an optical line terminal to (1) receive a digital broadcasting signal from a broadcasting network and first communication signal from an internet protocol network, and (2) transmitting the received
10 broadcast and the first communication signal as a single integrated optical signal;

an optical network terminal/optical network unit) as a user-side device for transferring (1) the integrated optical signal, from the optical line terminal, to a service user, and (2) user data from the service user to the optical line terminal;

a first WDM demultiplexer for WDM-demultiplexing the single
15 broadcast/communication-integrated optical signal from the optical line terminal, and transferring it to the optical network terminal/optical network unit; and

a first WDM multiplexer for WDM-multiplexing the user data from the optical network terminal/optical network unit and transferring it to the optical line terminal.

In accordance with another aspect of the present invention, a WDM-PON
20 (Wavelength Division Multiplexing-Passive Optical Network) is provided that enables the integration of broadcast and communication data, comprising:

an optical line terminal to (1) receive a digital broadcasting signal from

broadcasting network and a first communication signal from an Internet protocol network, and (2) transmitting the received broadcast and the first communication signals as a single integrated optical signal;

an optical network terminal/optical network unit) as a user-side device for
5 transferring (1) the single integrated optical signal, from the optical line terminal, to a service user, and (2) user data from the service user to the optical line terminal using an optical signal having a wavelength different from the integrated optical signal; and

a first WDM multiplexer/demultiplexer for 1) receiving and WDM-demultiplexing the single integrated optical signal from the optical line terminal, 2) transferring the
10 integrated optical signal to the optical network terminal/optical network unit, 3) WDM-multiplexing the user data from the optical network terminal/optical network unit, and 4) transferring the user data to the optical line terminal.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more clearly understood from the following detailed
15 description taken in conjunction with the accompanying drawings, in which:

Fig. 1 shows one prior-art example of a WDM-PON;

Fig. 2 shows another example of a WDM-PON;

Fig. 3 shows a WDM-PON that enables the integration of broadcast and communication services, according to one embodiment of the present invention;

Fig. 4 illustrates that communication and broadcast services are multiplexed using FDM;

Fig. 5 illustrates that communication and broadcast services are multiplexed using TDM;

5 Fig. 6 shows a WDM-PON that enables the integration of broadcast and communication services, according to another embodiment of the present invention; and

Fig. 7 shows an embodiment of a system that includes a plurality of parallel-connected WDM-PONs that enables the integration of communication and broadcast services according to the present invention.

10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will be described in detail with reference to the annexed drawings. In the following description, well-known functions or constructions are not described in detail since they would obscure the invention in unnecessary detail.

15 Fig. 3 shows a WDM-PON that enables the integration of broadcast and communication services, according to one embodiment of the present invention. As shown, the WDM-PON includes an OLT 31, ONT/ONUs 32, a WDM demultiplexer 33, and a WDM multiplexer 34. The OLT 31 is connected to a digital broadcasting network for broadcasting services, which is also referred to as a “broadcasting network”, and an IP
20 network for communication services. The OLT 31 receives digital broadcast signals from

the broadcasting network and communication signals from the IP network. The OLT 31 transmits the received broadcast and communication signals as a single optical signal after their photoelectric conversion. The OLT 31 transfers communication signals, received from service users, to the IP network. The ONT/ONUs 32 are devices on the user side for transferring the digital broadcast and communication signals, received from the OLT 31, to the service users, and transferring communication signals from the service users to the OLT 31. The WDM demultiplexer 33 WDM-demultiplexes the digital broadcast and communication signals λ_1 to λ_{32} , and transfers them to the ONT/ONUs 32. The WDM multiplexer 34 WDM-multiplexes the communication signals λ_1 to λ_{32} from the ONT/ONUs 32, and transfers them to the OLT 31. It is noted, that for illustrative purposes, reference is made to 32 lines of subscribers (ONT/ONU), but it is to be noted that it is only an example and the present invention is not limited to 32 lines.

For analog broadcast transmission, the OLT 31 includes an optical amplifier 310 for amplifying an analog broadcast signal, and an optical coupler 320 for combining the analog broadcast signal with digital broadcast and communication signals. Accordingly, the WDM-PON further includes an optical splitter 35, a photoelectric converter 36, and a RF splitter 37. The optical splitter 35 splits the broadcast and communication signals from the OLT 31 into an analog broadcast signal λ_A and digital broadcast and communication signals λ_1 to λ_{32} , and transmits the split signals. The photoelectric converter 36 photoelectrically converts the analog broadcast signal λ_A into an electric analog broadcast signal. The RF splitter 37 distributes the electric analog broadcast signal to each of the

ONT/ONUs 32.

In particular, the OLT 31 includes a broadcast switch 311, a broadcast channel controller 312, a first Ethernet switch 313, a communication/broadcast multiplexer 314, a second Ethernet switch 315, an optical transmitter 316, an optical receiver 317, a WDM multiplexer 318, and a WDM demultiplexer 319. The broadcast switch 311 switches MPEG (Motion Picture Experts Group) broadcast data. The broadcast channel controller 312 selects a broadcast channel according to a service user's request. The first Ethernet switch 313 switches the communication data into the higher-level IP network or into the communication/broadcast multiplexer 314 for its transmission to the ONT/ONU 32. The communication/broadcast multiplexer 314 multiplexes the communication data and the digital broadcast data. The second Ethernet switch 315 switches communication data from the service user and channel information of digital broadcast desired by the service user. It also separates the communication data from the channel information. The optical transmitter 316 electro-optically converts the multiplexed communication/broadcast data. The optical receiver 317 photoelectrically converts the communication data from the service user from the ONT/ONU 32. The WDM multiplexer 318 multiplexes wavelength-by-wavelength signals that are optically modulated. The WDM demultiplexer 319 separates the optical signals, from the ONT/ONUs 32, from each other on a wavelength-by-wavelength basis. The OLT 31 may further include an optical amplifier 310 to amplify analog broadcast signals for analog broadcast transmission, and an optical coupler 320 to combine the analog broadcast signal with the communication and digital broadcast signals.

The ONT/ONU 32 includes an optical receiver 323, a communication/broadcast demultiplexer 321, a hub switch 322, and an optical transmitter 324. The optical receiver 323 photoelectrically converts communication/broadcast optical signals from the OLT 31. The communication/broadcast demultiplexer 321 separates the communication signal from the digital broadcast signal. The hub switch 322 joins together communication data from a service user and digital broadcast selection data for selecting a digital broadcast channel desired by the service user. The optical transmitter 324 performs an electro-optical conversion on the data for its transmission to the OLT 31.

The downstream transmission operation of the WDM-PON of Fig. 3 is further described below. The downstream transmission represents transmission from the OLT 31 to the ONT/ONU 32. MPEG digital broadcast data from an Service Operator (SO), etc., is inputted to the broadcast switch 311. Each service user assigns a TV channel that he or she wants to see. The broadcast channel selection controller 312 transfers a signal for assigning the TV channel to the broadcast switch 311 to select a digital broadcast channel wanted by each service user. Each service user may request a number of digital broadcast channels and up to K digital broadcast channels are switched. Thus, the maximum number of transmittable digital broadcast channels are set as a specification of the WDM-PON, because a number of broadcast receivers may be equipped in a single residence.

Communication data transmitted from the higher-level IP network is switched in the first Ethernet switch 313 on a user-by-user basis. The communication data, together with the digital broadcast signals, is then inputted to the communication/broadcast multiplexer 314. The communication/broadcast multiplexer 314 multiplexes the communication and

broadcast data into a single channel using a multiplexing method, such as Time Division Multiplexing (TDM) and Frequency Division Multiplexing (FDM).

Fig. 4 illustrates that the communication and broadcast services/data are multiplexed using the FDM. Fig. 5 illustrates that they are multiplexed using the TDM. In Fig. 4, the communication data 41 is positioned in the baseband, and K digital broadcast data 42 and 43 are positioned in the passband. In Fig. 5, the communication data and the K digital broadcast data exist on the time axis, as a time packet.

The communication and digital broadcast data from the communication/broadcast multiplexer 314 are electro-optically converted in the optical transmitters 316. The optical transmitters 316 have unique transmission wavelengths λ_1 to λ_n , respectively.

After being multiplexed in the WDM multiplexer 318, the optically-modulated, the optical coupler 320 combines the communication/broadcast data, with an analog broadcast optical signal of λ_A amplified in the optical amplifier 310.

The combined wavelength-multiplexed optical signal is transmitted through an optical cable. The analog broadcast optical signal λ_A is separated from the combined optical signal by an optical splitter 35 on the receiver side. The communication/broadcast-multiplexed optical signals of λ_1 to λ_n are separated from each other by the WDM demultiplexer 33 according to their wavelength. They are also photoelectrically converted by the optical receiver 323 in each ONT/ONU 32.

The communication/broadcast demultiplexer 321 demultiplexes the photoelectric-converted communication/broadcast multiplexed signal into K digital broadcast channels

and communication data. Then they are transferred to a terminal device of the service user, such as a digital TV and a computer.

After the analog broadcast optical signal split through the optical splitter 35 is photoelectrically converted, the converted electrical signal is split through the RF splitter
5 37 to be transferred to each service user.

The upstream transmission operation of the WDM-PON of Fig. 3 is further described below. The upstream transmission represents transmission from the ONT/ONU 32 to the OLT 31. Signals transmitted from each service user to the OLT 31 are composed mainly of IP communication data generated by a computer, etc., and a broadcast channel
10 selection signal for viewing a desired broadcast channel. The hub switch 322 in the ONT/ONU 32 combines the IP communication data and broadcast channel selection signal. They are electro-optically converted in the optical transmitter 324 with a transmission wavelength assigned to each of the ONT/ONUs 32. Then they are multiplexed in the WDM multiplexer 34 with wavelength signals from the other ONT/ONUs 32.

15 The multiplexed WDM optical signals are transmitted to the OLT 31 through an optical cable. The WDM demultiplexer 319 in the OLT 31 separates the signals from each other according to their wavelength.

Thereafter the wavelength signals are photoelectrically converted in the optical receiver 317. The converted electrical signals are each inputted to the second Ethernet
20 switch 315. In the Ethernet switch 315, the broadcast channel selection signal is switched to the broadcast channel selection controller 312, and the IP communication data is switched to the first Ethernet switch 313 connected to the IP network.

The signals received by the broadcast channel selection controller 312 are used for controlling the broadcast switch 311. The signals transmitted to the first Ethernet switch 313 are transferred to the higher-level IP network.

Fig. 6 shows a WDM-PON that enables the integration of broadcast and communication services/data, according to another embodiment of the present invention.

The embodiment shown in Fig. 6 differs from the embodiment shown in Fig. 3. in that the downstream wavelengths λ_1 to λ_n and upstream wavelengths λ_{n+1} to λ_{2n} are different. Thus, a single WDM multiplexer/demultiplexer 618 in OLT 61 and a single WDM multiplexer/demultiplexer 63 in ONT/ONU 62 are required.

The operation and configuration of this embodiment is similar as that of the embodiment of Fig. 3, except that a single WDM multiplexer/demultiplexer is used in each of the OLT 61 and ONT/ONU 62 because the upstream and downstream wavelengths are different from each other.

Fig. 7 shows an embodiment of a system that includes a plurality of parallel-connected WDM-PONs that enables the integration of communication and broadcast services according to the present invention. As shown, a WDM-PON network accommodates L WDM-PON OLTs 707 and L x n ONT/ONUs 715, as further described below.

A digital/analog broadcast separator 702 separates analog and digital broadcast signals from an SO or a Digital Media Center (DMC) 701. The digital broadcast provided in this manner includes a digital image signal.

A digital broadcast channel-by-channel separator 703 separates the digital broadcast into its individual MPEG digital broadcast channels. The separated digital broadcast channels are each split into L ones through a splitter 704, and then transmitted to WDM-PON OLTs 707.

5 Communication data transmitted from an IP network 705 is switched in a high-capacity Ethernet switch 706 (or an IP router), and then transmitted to each of the WDM-PON OLTs 707.

The communication and broadcast data transmitted to the WDM-PON OLT 707 is transmitted to each ONT/ONU group, as described above in reference to Fig. 3.

10 Optical amplifier 708, optical splitter 709 and optical coupler 710 are used to combine an analog broadcast signal, from the digital/analog broadcast separator 702, with each of the OLT outputs. It is the transmitted to each ONT/ONU group through an optical cable.

In each ONT/ONU group, an analog broadcast optical signal is split through an
15 optical splitter 711. Thereafter, it is photoelectrically converted by a photoelectric converter 712 and transmitted to each ONT/ONU 715 through a RF splitter 713.

Communication/broadcast multiplexed optical signals of λ_1 to λ_n are separated from each other through a WDM demultiplexer 714 according to their wavelength. Then they are transmitted to the ONT/ONUs 715, respectively.

20 Upstream data transmission and broadcast channel selection methods in the embodiment of Fig. 7 are similar to those described in reference to Fig. 3.

The present invention provides a WDM-PON system that enables the integration of broadcast and communication services, thus providing subscribers with high-speed and high-capacity data and broadcast services using a wavelength division multiplexing scheme. Advantageously, a low-priced WDM-PON system for communication/broadcast-integrated services is achieved, because digital broadcast data is multiplexed with communication data. Thus, the need to accommodate digital broadcast is accomplished without the need to replace existing coaxial cable.

In addition, because communication/broadcast services are provided to subscribers through a single wavelength, it is possible to accommodate a larger number of subscribers, therefore providing an effective optical subscriber network for future requirements, such as with the future advent of Fiber To The Home (FTTH).

Although the preferred embodiments of the present invention have been disclosed for illustrative purposes, those skilled in the art will appreciate that various modifications, additions and substitutions are possible, without departing from the scope and spirit of the invention as disclosed in the accompanying claims.